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Methodology for Microscopic Traffic Simulation Modelling of Land Port of Entries along the U.S.-Mexican Border: Ysleta – Zaragoza Land Port of Entry Case Study

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Abstract

Land Ports of Entry (LPOEs) are facilities that control access into the U.S., as well as departures of persons and freight. While traffic simulation modeling techniques are not typically used to evaluate LPOE operational processes, they should be considered more often, because LPOEs have a significant impact on surrounding traffic conditions and vice versa. This paper proposes a methodology for developing microscopic traffic simulation models of LPOEs along the U.S.-Mexico border. The methodology consists of seven steps: (i) collect data; (ii) develop traffic or roadway network; (iii) model inspection and toll booths; (iv) develop traffic management strategies; (v) set up traffic demand; (vi) calibrate model; and (vii) validate model. The paper also presents a case study in which this methodology was followed to develop the Ysleta – Zaragoza LPOE traffic simulation model, which can be controlled from a web-based interface to help LPOE personnel without previous transportation modeling experience.

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Keywords: traffic simulation; border-crossing; traffic operations; Port of Entry.

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1. Introduction and Objectives

Land Ports of Entries (LPOEs) are facilities that control access and egress of people and freight to the U.S.[1]. LPOEs can consist of one or more of the following border crossings categories: (i) bridges; (ii) tunnels; (iii) roadway crossings; (iv) rail crossings; (v) bicycle crossings; (vi) pedestrian crossings; or (vii) livestock crossings.

Personnel and facilities from U.S. Customs and Border Protection (CBP) and Aduanas are always present at every U.S.-Mexico LPOE[1,2.] Aduanas is the Mexican customs agency that operates inspection booths in southbound direction (i.e., from U.S. to Mexico); CBP is in charge of the U.S. customs and immigration affairs, and operates inspection booths in northbound direction (i.e., from Mexico to U.S.). In some cases, travelers have to pay a toll for using the facility; LPOE operators are in charge of operating toll booths where toll fees are collected. Toll booths are located at the entrance of LPOEs. Inspection processes followed at U.S. and Mexican inspection booths have a significant impact on wait times, as well as congestion levels at LPOE surroundings.

The use of traffic simulation models as decision support tools could help LPOE personnel to evaluate traffic conditions at LPOEs and their surroundings in real time. Information obtained from these tools may be incorporated into decision making processes at LPOEs to expedite cross border operations. The unique characteristics of LPOEs require a high level of detail, and mesoscopic models are not suitable for highly granulated data analysis. Hence, LPOEs should be microscopically modeled to provide a detailed representation of their hourly traffic processes. Microscopic traffic simulation models represent individual vehicle movements, and are becoming an important tool for traffic analysis and management[3]. Microscopic traffic simulation models are very useful to assess traffic operational strategies and policies, performance of Intelligent Transportation Systems (ITS), or to evaluate decisions to be taken under special circumstances such as traffic incidents[4].

Since 2011, various efforts have been made regarding LPOE traffic simulation modeling. Shelton (2011) developed a traffic simulation model capable of replicating commercial lanes (i.e., truck lanes) at the Bridge of the Americas (BOTA)[5]. This Bridge is located in the El Paso – Ciudad Juarez bi-national region. Northbound passenger vehicle lanes at BOTA Bridge were modeled by Galicia et al.[6] to estimate losses in productivity, associated with delays in border crossing operations. The University of Texas at El Paso developed a traffic microsimulation model of the Ysleta – Zaragoza LPOE - located in the El Paso – Ciudad Juarez bi-national region[7]. All these studies present results of traffic models that replicate LPOE operations. However, none propose a methodology for developing, calibrating and validating LPOE traffic simulation models at the microscopic level. These studies also do not provide any web-based methods to evaluate current traffic conditions and proposed scenarios.

The methodology presented herein could be useful to traffic practitioners for developing, calibrating and validating passenger vehicle LPOE traffic microsimulation models along (but not limited to) the U.S.-Mexico border. This methodology covers all steps involved in the traffic simulation process from data collection to model validation. This paper also identifies different challenges that modelers may encounter when developing the model, especially those related to the limited data availability due to security policies typically imposed at LPOEs. Finally, this paper presents an intuitive web-based interface capable of performing basic operational evaluations of the Ysleta-Zaragoza LPOE. The web-based interface aims to facilitate the use of the Ysleta-Zaragoza traffic simulation model to LPOE personnel without traffic modeling background.

2. Proposed Methodology

This section presents the methodology for creating a traffic simulation model capable of realistically replicating operational procedures at passenger vehicle lanes that connect Mexico to the U.S. and predicting future conditions under different circumstances. The methodology consists of seven steps: (i) data collection; (ii) network development; (iii) inspection and toll booths; (iv) traffic management strategies; (v) traffic demand; (vi) model calibration; and (vii) model validation.

2.1. Data Collection

The process of developing the LPOE traffic simulation model starts with collecting data relating to the facility and its operational processes in northbound and southbound directions. These data consist of traffic volumes entering the facility, the number of inspection and toll booths opened each hour, the average wait time per hourly period (for southbound and northbound direction), the geometry of traffic lanes, speed limits, the manual and or automatic toll collection operational time, and the inspection time at inspection booths.

2.2. Network Development

The LPOE traffic simulation network consists of three elements: (i) road network; (ii) vehicle origins; and (iii) vehicle destinations. During the road network coding process, the modeler should be able to accurately code road geometry. Microscopic simulation packages allow introducing different parameters to replicate the road network subjected to analysis. Vehicle origin and destinations are coded as centroids, which can be formally defined as origins and/or destinations of vehicles[8]. To correctly code a centroid, it is necessary to define the number of vehicles that have the subject centroid as their origin and destination per hour. Every LPOE should have at least two centroids which generate traffic volumes into the LPOE, and are also the destination of traffic volumes exiting the LPOE. Traffic volumes collected at both entrances of the LPOE should be used to code hourly volumes generated by each centroid.

2.3. Inspection and Toll Booths

Inspection booths are located at the border to control the movement of freight and travelers, and to enforce immigration and/or commercial regulations of the destination country. Inspection time is unpredictable and it is based on security protocols implemented by CBP. Inspection booths and toll booths can be coded, in microsimulation, as stop signs, delay metering points or toll plazas. These inspection and toll booths need to be subjected to a control plan that specifies the probabilistic distribution associated with the inspection and toll collection times for a specific hour interval. For modeling purposes, inspection time variable can be considered as stochastic and used for calibrating the model. Toll collection time (both manual and automatic) can be obtained directly in the field.

2.4. Traffic Management Strategies

Traffic management strategies consist of a group of policies developed by CBP, Aduanas, and LPOE operators. Policies consist of a set of actions: control plan changes, lane closures, and forced turns. Control plans specify the probabilistic distribution associated with both inspection and toll collection times for a specific one-hour interval. This probability distribution is defined by inspection mean time or toll collection mean time, along with standard deviation. Lane closures and forced turns do not allow its associated vehicles to use booth inspections which are closed in a specific hourly interval (based on CBP policies).

2.5. Traffic Demand

Traffic demand is the development of Origin-Destination (O/D) matrices based on traffic volumes captured in the field. The cells of an O/D matrix contain the number of vehicles per time period, travelling from the origin to the destination centroid. One O/D matrix per hour describes the traffic volumes entering the LPOE in sufficient detail.

2.6. Model Calibration

During the calibration process, various parameters and/or attributes of the model are adjusted to obtain model outputs close to data observed in the field. Different methodologies for calibrating traffic microsimulation models have been proposed in the literature. However, none of them propose a full calibration process that can be applied to any model[9].

2.7. Model Validation

Traffic model validation is the process that compares the parameters estimated by the model with those observed in the field[10]. Both northbound and southbound directions are validated when wait times resulted from the traffic simulation model are within the ±10 percent absolute error range in comparison with wait times reported in the BCIS website.

3. Ysleta-Zaragoza LPOE Case Study

The case study presented in this section follows all steps proposed in the methodology presented in this paper. This case study should help modelers use the methodology properly, and includes a web-based interface to facilitate the use of the model by LPOE personnel without previous modeling experience. The case study presented is the Ysleta-Zaragoza LPOE. Commonly known as the Zaragoza Bridge, the LPOE is one of the four that connect El Paso (Texas, USA) to Ciudad Juarez (Chihuahua, Mexico). The Ysleta-Zaragoza traffic simulation model replicates traffic conditions of a typical mid-week day. The Ysleta Zaragoza model was developed using Aimsun traffic simulation package[11]. However, the methodology can be used with other traffic simulation packages available on the market such as Vissim (PTV Group) or TransModeler (Caliper). This traffic simulation packages are capable of simulating individual vehicles while they travel through the network, according to car following and lane changing theories. This model can show bottlenecks and congestions, queue formations, queue spillbacks, etc. Fig. 1 presents an aerial view of the Ysleta-Zaragoza LPOE Aimsun network.

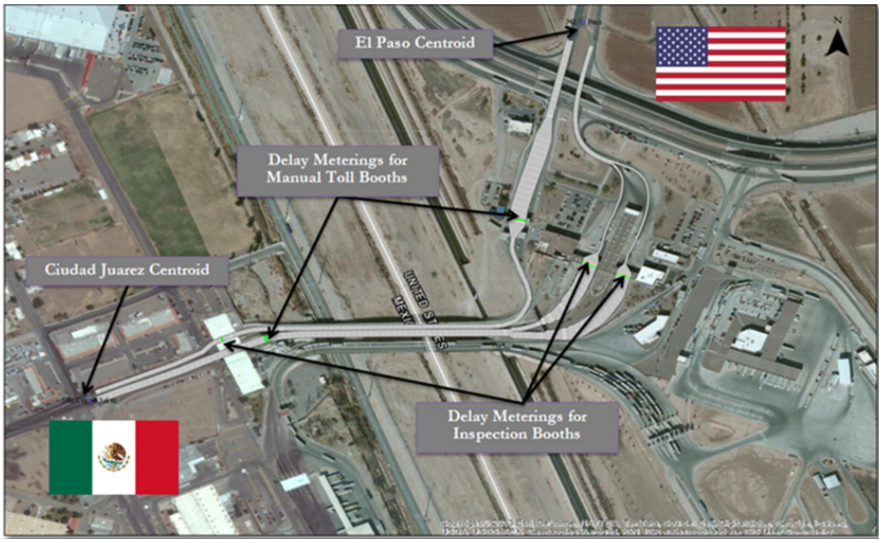
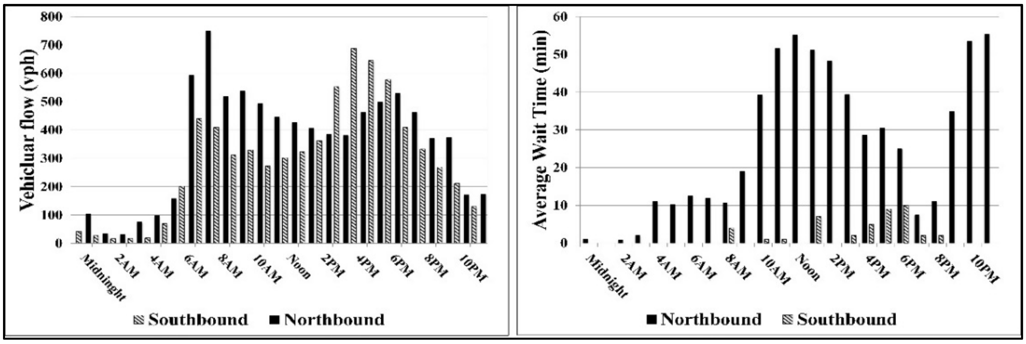


Fig. 1. Ysleta-Zaragoza LPOE

3.1. Data Collection

Traffic volumes entering the Ysleta-Zaragoza LPOE using the southbound entrances (i.e., U.S. to Mexico) were obtained from the U.S. LPOE operator, the City of El Paso. However, the traffic volumes using northbound entrances (i.e., Mexico to U.S) were not provided by the Mexican LPOE operator. Hence, the research team collected traffic volumes at northbound exits (i.e., U.S. side) by using a video recording trailer. It was assumed that these volumes are equal to the traffic volumes at northbound entrances. Northbound and southbound traffic volumes for the Ysleta-Zaragoza traffic simulation model are shown in Fig. 2. Hourly average wait times for passenger vehicles at northbound and southbound entrances were obtained from the Border Crossing Information System

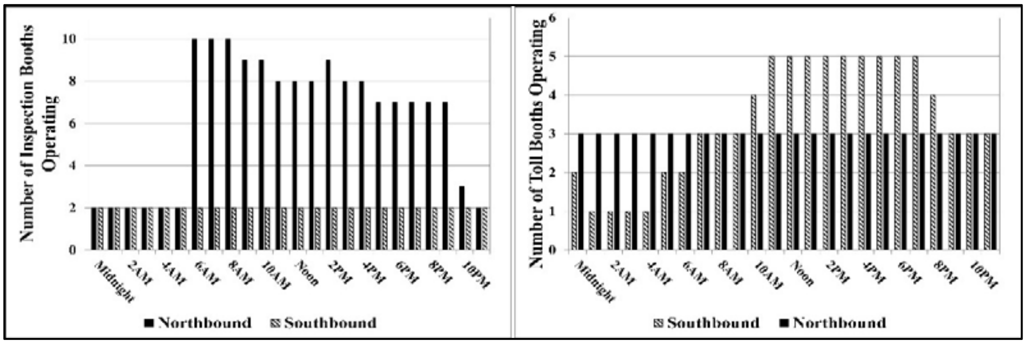
(BCIS)[12]. Fig. 2 also shows the average wait times in both directions at the Ysleta-Zaragoza LPOE in minutes.



(a) Traffic volumes per hour; (b) Average wait time

Fig. 2. Ysleta-Zaragoza LPOE traffic volumes and wait time

The number of northbound inspection booths open per hour can be obtained from the CBP Border Wait Times website[13]. For the southbound direction, there is no official information source, so the data were collected in the field. Similarly, the northbound number of toll booths operating per hour (Mexico side) was also collected in the field. Finally, southbound number of toll booths operating per hour was directly obtained from the City of El Paso (U.S. operator). Fig. 3 presents the number of inspection and toll booths operating per hour in the Ysleta-Zaragoza LPOE.



(a) Inspection booths; (b) Toll booths

Fig. 3. Number of inspection and toll booths operating per hour in the Ysleta-Zaragoza LPOE

Geometry and width of lanes were obtained from aerial imagery, and speed limits from the internet mapping resources or directly from the field. In the Ysleta-Zaragoza traffic simulation model, the geometry of the road was coded by means of web mapping services. The speed limit obtained from the field was 30 miles per hour (mph).

3.2. Network Development

The Ysleta-Zaragoza LPOE network consists of 5 delay metering points, 19 sections, 17 nodes, and 2 centroids (see Fig. 1).

3.3. Inspection and Toll Booths

Inspection time and toll collection time are part of the traffic management strategies coded in the microscopic traffic simulation model of the LPOE. In the Ysleta-Zaragoza LPOE, mean toll collection time adopted was five seconds with a standard deviation of three seconds based on data gathered from the field. Inspection time variable can be considered as stochastic and was used for calibrating the model.

3.4. Traffic Management Strategies

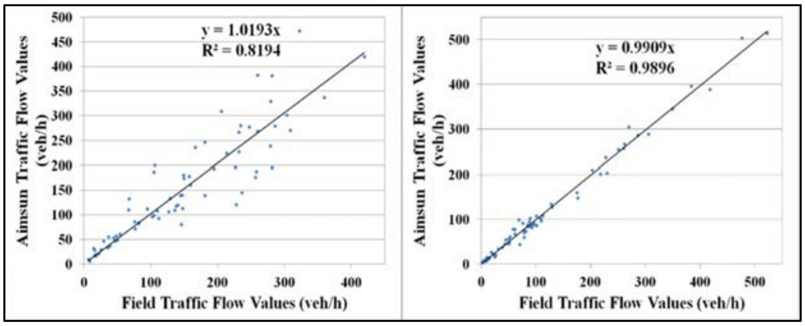
In the Ysleta-Zaragoza LPOE traffic simulation model forced turns are used when the complete branch is closed for traffic. Moreover, lane closure strategies are used when specific lanes are closed for traffic. A total of 24 strategies were created – one for each hour of simulation.

3.5. Traffic Demand

The cells of the Ysleta-Zaragoza LPOE traffic simulation model were filled out with number of vehicles per hour travelling from the Ciudad Juarez centroid to the El Paso centroid and vice versa.

3.6. Model Calibration

In the Ysleta-Zaragoza LPOE, calibration was done by matching hourly traffic volumes collected in the field for three days, (i.e. a total of 72 hourly volumes), and the hourly traffic volumes modeled (see Fig. 4). To successfully calibrate the model, the team had to adjust behavioral parameters to increase the willingness of drivers to overtake other vehicles when a certain gap is available. These behavioral parameters are numerical and can be changed by the modeler. The team also reduced vehicle headways and modified inspection times at inspection booths.

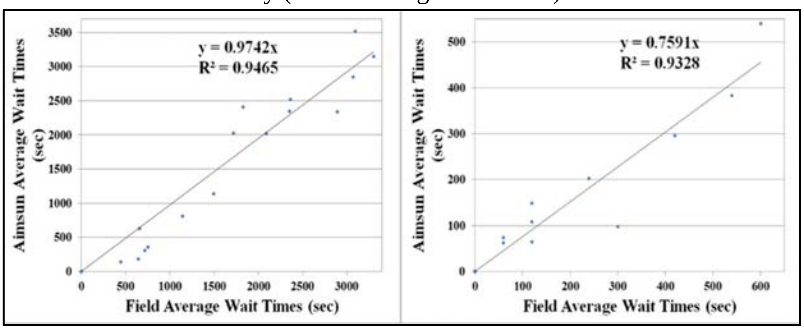


(a) Northbound; (b) Southbound

Fig. 4. Calibration Results for NB and SB Direction

3.7. Model Validation

In the Ysleta-Zaragoza LPOE traffic simulation model, both northbound and southbound directions are validated when wait times resulted from the traffic simulation model are within the ±10 percent absolute error range in comparison with wait times reported in the BCIS website. Fig. 5 presents validation results for both northbound and southbound directions in the model for one day (i.e. 24 average wait times).



(a) Northbound; (b) Southbound

Fig. 5. Validation Results for NB and SB direction

4. Results and Discussion

The unique characteristics of LPOEs require the use of a particular traffic simulation methodology. The methodology proposed in this paper allows traffic modelers to develop microscopic traffic simulation models capable of replicating hourly processes implemented in LPOEs. The use of this methodology when developing a LPOE microscopic traffic simulation model could save a significant amount of time and resources.

The final objective of the case study presented in this paper is to develop an intuitive web-based interface capable of performing basic operational evaluations of the Ysleta-Zaragoza LPOE. The web-based interface will allow LPOE personnel and decision makers to perform traffic operation evaluations in real time. Results of these traffic operation evaluations could be incorporated in the LPOE decision making process. The web-based interface could be used by any LPOE personnel with or without previous experience in traffic engineering or modeling.

The Ysleta-Zaragoza traffic simulation model was developed following the methodology presented in this paper. Once the traffic simulation model was calibrated and validated, the research team uploaded it to a server. Then, the team developed a web-based interface to run the model and control some of its parameters. The web-based interface is intuitive and incorporates the following elements:

- *Traffic Demand*. The user can select the traffic volume entering the network using a dropdown menu. A 100 percent demand means that the traffic volume entering the LPOE is equal to the volumes observed in the field a typical mid-week day at the Ysleta-Zaragoza LPOE. A demand of 90 percent corresponds with a 10% traffic volume reduction of the observed traffic volumes. Finally, a demand of 110 percent corresponds with a 10% traffic volume increase of the observed traffic volumes.
- *Flow Strategies*. The user can select from four strategies defined by the model:
  - Free flow: The model simulates the LPOE without taking into account any policies. So, toll and inspection booths do not operate and there are no lane closures.
  - Current Strategy: This strategy was developed based on the current practices at Ysleta-Zaragoza LPOE. This strategy is calibrated and validated in the Aimsun model.
  - Aggressive Strategy: This strategy was specifically designed to reduce congestion. It is based on the current strategy, but it keeps larger number of inspection booths open. This strategy is recommended when the congestion levels are high, and there is enough staff available to serve extra inspection booths.
  - Conservative Strategy: This strategy was specifically designed to reduce LPOE operation costs. It is based on the current strategy, but it keeps a lower number of inspection booths opened. The conservative strategy is recommended when congestion levels are low.
- Output. After running the simulation (approximately 1 to 3 minutes), the results are displayed in the browser. Specifically, the user can see the results of three variables simulated: i) delay time expressed in seconds per mile; ii) travel time expressed in seconds per mile; and iii) mean queue expressed in number of vehicles. The interface displays a line chart that presents hourly values of each variable for the 24-hour period modeled.

5. Conclusion

The approach proposed in this paper allows traffic modelers to develop microscopic traffic simulation models capable of replicate hourly processes implemented at LPOEs. Traffic simulation model techniques are not typically used to evaluate LPOE operational processes. However, since all operational processes followed at LPOEs have a significant impact on traffic conditions at their surroundings and vice versa, the traffic models should be considered in LPOE decision-making processes. The Ysleta-Zaragoza LPOE experience high congestion levels from 1:00 p.m. to 12:00 a.m. The situation is similar in most of the LPOEs which connect the United States to Mexico, that represents a significant amount of economic and productivity loss. Based on this study, several conclusions can be reached:

- LPOE personnel can evaluate the impact of opening or closing inspection booths during specific periods of time using microscopic traffic simulation models;
- Microsimulation can help LPOE in decision making process to implement improved traffic operational strategies and policies that expedite border crossing operations along the U.S. border. Consequently, economic

losses may be reduced, and emissions of pollutants from vehicles to the atmosphere may also be reduced as well;

- Further efforts for calibrating the Ysleta-Zaragoza traffic simulation model can be made for improving the model accuracy;
- The web-based interface provide LPOE personnel with an intuitive interface – convenient for evaluation of various scenarios within minutes. Previous knowledge in traffic simulation modeling is not required for using this web-based interface;
- It is highly recommended to use real time traffic volume data to be able to assess operational processes at LPOEs in real-time;
- Results of these traffic operation evaluations performed with the web-based interface could be incorporated in the LPOE decision making process, or could be used for evaluation of congestion pricing alternatives.

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